The cosmos has a unique attribute - cheap clean, super-ultra-high vacuum (unachievable on Earth), which can be used for epitaxy growth of III-Vs, II-VIs and IV-IVs semiconductors and can be further used for thin film growth using space-born atomic oxygen.

Sergei Chikichev

Russia & US plan MBE research

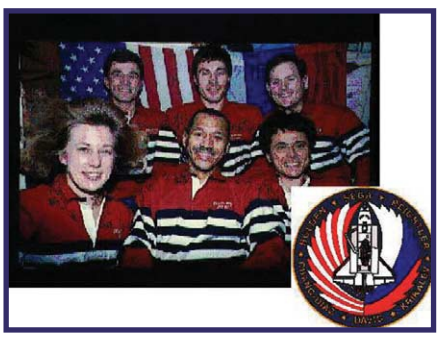
A pioneer in space MBE, Prof Alex Ignatiev from University of Houston and NASA visited Russia to discuss collaboration with Russian colleagues to revive the Wake Shield (WSF) MBE experiments in space, relying heavily on Russia's capabilities and on-going R&D in the field.

III-Vs Review was told the news by Prof. Oleg Pchelyakov, Head of the MBE department at the Institute of Semicon-ductor Physics, Siberian Branch, the Russian Academy of Sciences (ISP SB RAS) in Novosibirsk, who arranged the visit.

Director of Texas Center for Superconductivity and Advanced Materials at University of Houston, Prof Ignatiev was invited to the Russian Federation by the ISP SB RAS for an official visit from July to August, 2004.

Among the events in Prof Ignatiev's scheduled stay in the Russian Federation was a visit to Khrunichev's Construction Bureau "Salyut"(Moscow) with joint presentations on the US WSF project and the Russian "Ekran" (Shield) project, with discussions about opportunities for collaboration leading to the project "Ekran" ("Shield") as a joint project for the International Space Station.

Figure 1: The STS-60 Space Shuttle Crew. Left to right: (rear) Ron Sega, Sergei Krikalev, Ken Reightler; (front) Jan Davis, Charlie Bolden, Franklin Chang-Diaz



Subsequently Professor Ignatiev visited Korolëv's Russian Space Corp "Energiya" in Korolev township for joint presentations on the WSF and the Ekran projects and discussions on the perspectives of a cooperation between ISP, the University of Houston and RSC"Energiya" on the "Ekran" project. Prof Ignatiev also visited the Centre for Cosmonaut Training, Zvëzdnyi Gorodok, before travelling to St-Petersburg to visit the Ioffe Physico-Tech -nical Institute, where participation of the Institute in the joint "Ekran" project was discussed.

Prof Ignatiev also visited ISP Novosibirsk, for a presentation at a scientific seminar, and for formal discussions on a cooperative Ekran project, with the signing of a Memorandum of Understanding for joint efforts in the development of thin film epitaxy in space behind a molecular shield.

Background

An open literature search reveals that currently only two countries (USA and Russia) are involved in materials science work using space vacuum. An American project was initiated in 1985 by Profs. Paul Chu and Alexei Ignatiev who a year later founded the "Space Vacuum Epitaxy Center" at the University of Houston.

This R&D can be regarded as a revitalisation of an earlier concept on the generation of ultra-high vacuum in low earth orbit space, proposed in the early seventies by R. J.Naumann from NASA Marshall Space Flight Center. At that time potential users were not interested in the possible outcome of a space vacuum programme.

In the last decade of the past century some analytical reviews by top Russian experts in microelectronics technology (Academician K.G. Valiev and Prof A.A. Orlikovskii) appeared, where it was predicted that the internal logic of technology evolution would unavoidably put the super-ultra-high vacuum of space in high demand [1]. The timing of these publications coincided with first experiments by Ignatiev and his team on the Shuttle (in February 1994, STS-69, *Discovery*; September 1995, STS-69, *Endeavour*; and November 1996, STS-80 *Columbia*).

In these experiments on semiconductor thin film growth in space (Fig. 1) Russian cosmonaut Sergei Krikalev was involved as a flight engineer. The space experiments confirmed in general the unique opportunities of MBE growth using the WSF, which provided vacuum conditions simply unattainable on earth due to literally infinite pumping speed for any gaseous molecules (inert gases included).

Since priority issues are always important, Prof Oleg Pchelyakov, became deeply interested in answering the eternal question "Who was the first?" and was able to find the reference [2] where, seemingly for the first time, the idea of a molecular shield was proposed.

Greeks get there first

The basic idea, however, is deeply rooted in the history of humankind. In the C4th BC, Aristotle expressed the idea: "The emptiness (vacuum) is a space formed in the wake of the stone released from a

Figure 2: (L to R) Prof. Oleg Pchelyakov, Cosmonaut Sergei Krikalev, Prof. Alexei Ignatiev at the Solute-TM training apparatus at the Russian Space Corp "Energiya"

sling. But it immediately disappears since particles from the surroundings tend to fill the emptiness."

The only thing remaining to be done after Aristotle is to accelerate the 'stone" to the velocity of the particles in the surroundings and almost absolutely empty space will exist in the wake of the flying "stone". Thus it seems Aristotle should be properly regarded as author of the basic idea for production of super-ultra-high vacuum.

It is well known to all those involved that the history of vacuum techniques (and numerous technologies based on them), is in fact, a hard and continuous struggle for ultra-high and super-pure "space" vacuum, yet produced under restricted earth conditions.

Every success achieved by homo sapiens this way is contrary to earth's environment. The cost of present-day experimental and industrial apparatus for producing UHV amounts to millions of dollars. And maintenance costs increase significantly for every decade of pressure reduction in a given volume, due to increased quantities of energy, liquid nitrogen and liquid helium used for that purpose.

"After the disintegration of its own vacuum industry," points out Prof. Oleg Pchelyakov, "my country is compelled to buy such UHV instruments from abroad. As a rule, every purchase is accompanied by a business-plan, where the buyer expects to obtain some economic effect.

"Simple calculations show that the money spent for imports of such UHV-chambers is more than sufficient for the realisation of the whole "Ekran" project! And it seems almost impossible to estimate the capital investments for development of earth-based UHV facilities.

"The first Russian project on using super-ultra-high vacuum, the Shield Facility, was formulated (in a rush after the Wake Shield Facility programme) by a group of scientists from Zelenograd (Russia's 'Silicon Valley') who were involved in several programmes on space-based materials science research, headed by Evgeny Markov.

"A similar project was also presented by Prof. Petr Kop'ev from the Ioffe Institute (St-Petersburg). Strenuous objections were raised against both projects, but many items from both are now incorporated into the latest version of "Ekran".

"We are working in close cooperation with both groups and with specialists from the Russian Space Corp "Energiya" (Korolev City).

"These mutual efforts have resulted in a project for space experiments on compound semiconductor epitaxy on silicon substrates in a vacuum behind the "Shield." Recently we completed the draft stage of the project, designing the on-board technologies equipment. It is possible that in project realisation several other organisations will be involved, including Prof Ignatiev's original group.

"Right now we have solid agreement with Paton's Welding Institute from the Ukraine and Khrunichev's State Research-and-Production Space Center. An interesting suggestion from the latter is to use the "*Rokot*" carrier rocket, which must be destroyed anyway by so-called peaceful launching, for the

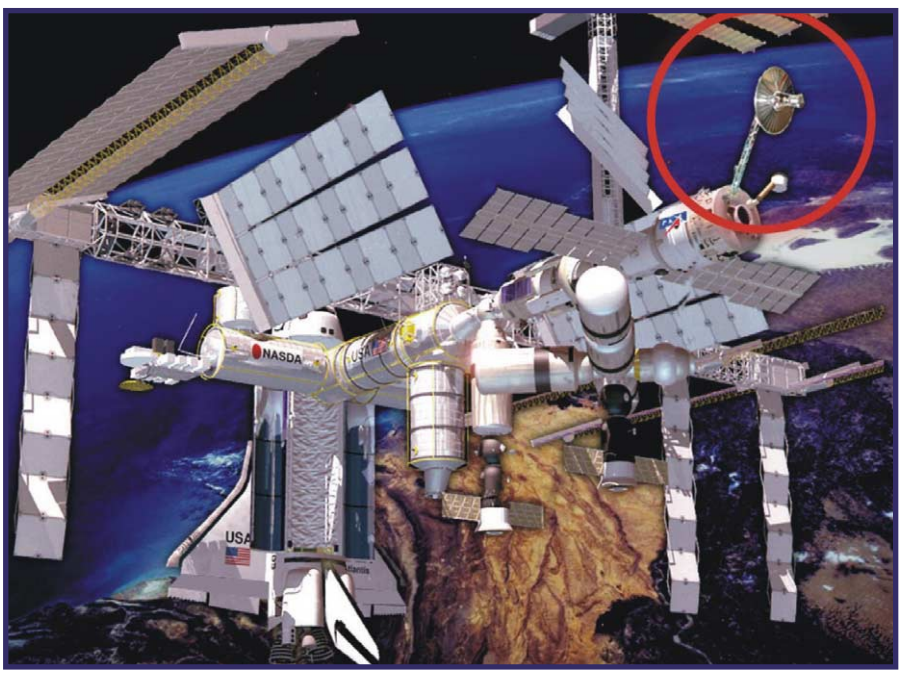


Figure 3: The International Space Station. Red circle designates the possible position for space MBE system.

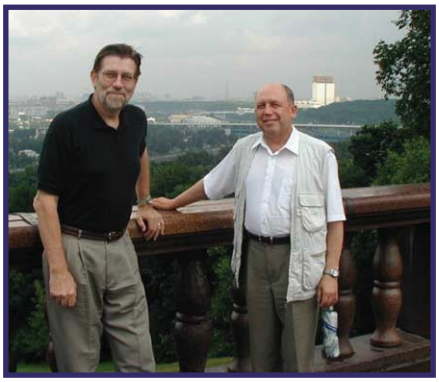


Figure 4: Ignatiev and Pchelyakov at the balcony of the Moscow State Unversity

space experiments. This may be the cheapest way to deploy TFT growth equipment in space.

Alex Ignatiev in Russia

"My acquaintance with Alex was made many years ago, quite accidentally and without formally meeting. I've visited the site of "Space Vacuum Epitaxy Center" at Houston University and have read the articles about his Wake Shield Facility project," recalls Prof Pchelyakov. "Precisely that project brought me ideas about also using the unique vacuum properties of free space as an ideal vacuum pump in the wake of a flying (at orbital velocity) stainless steel disc-shield.

"For many years, I regularly visited Alex's web site and references on his work greatly aided me to substantiate the necessity and prospects of a similar Russian project. In all my articles (and other works) about this Russian project ("Ekran") I always cite the achievements and difficulties of Alex's project.

Figure 5: Orlikovskii and Ignatiev in Pavlovsk

"Finally, in 2004, I risked emailing Alex directly and we immediately found a common language. We both valued the unique vacuum properties of space, and understood that after the tragic events with Space Shuttle "*Columbia*" the only way to proceed with MBE space experiments needs was by uniting our projects into one international project "Ekran"

"To progress this, I invited Alex to visit Russia. He responded very quickly and positively, and we finally met in Moscow on July 25, 2004. It was his second visit to his historic motherland, since some years ago he participated in a conference organised by Moscow State University. But that time-schedule was so tight he was simply unable to experience Russia.

"I prepared a detailed plan for his visit making arrangements with the authorities of ISP, "Energiya", Khrunichev's Center, "Salyut" and the Ioffe Institute. Provisions were also made for visiting some historical places in Russia. But the major outcome of the visit was, certainly, the signing of the Memorandum, the basic points of which were laid down during numerous conversions at Khrunichev, "Energiya", "Salyut", the Ioffe Institute and ISP.

"Quite unexpectedly, during the visit to "Energya", when one of the leading specialists of the Corporation (Alexander Ivanov) showed our delegation the Center of Cosmonaut's Training, we met Sergei Krikaliëv, training for a future mission on the "Salyut-TM" apparatus.

Ignatiev and Krikalëv met as old friends. It was my second meeting with our cosmonaut, and Alex and I took this opportunity to discuss with Sergei the idea of a joint cooperation to continue the development of MBE in space. He was very glad to meet us, and interested to hear about our possible joint activity in space MBE (Fig.2) saying he was ready to participate in the realisation of our project.

But the most productive discussions occurred on the high speed train *"Kras naya Strela"* ("Red Arrow") which

Figure 6: Alex Ignatiev in MCT MBE Lab of ISP

travels from Moscow to St-Petersburg, where Prof P S Kop'ev was to meet us. There we formulated important ideas that inject new life to both of our space projects.

MBE approach expands

"Now our work will be directed to the development of an absolutely new technology uniting earth-based achievements in the growth of multi-layer TF structures and nanostructures by a promising combination of MBE, CVD, CBE etc, only possible in space with its perfect pumping capability and minimal wall effects.

Our first step will be the assembly of a small-sized apparatus for synthesis of single crystalline layers from molecular beams and gas-phase jets on board ISS.

It will be used for approbation and technical validation of the concept and for student education. To this end a computer-based system will be created for control of the space-based film growth processes.

The system will be coupled to the Internet both for remote control and data acquisition by the research team, for educational opportunities for students, and as an information source for commercial interests in the microelectronics industry.

"We look for a productive collaboration and further development of MBE technology in space," concludes Prof. Oleg Pchelyakov,

References

1. *Electronics: Science, Technology, Business.* 1996, No5-6, p3-11.

2. R. N. Kostoff., 1970, *NASA Contract* Rep. CR-110456.